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Effect of plasma treatment on polyester knitted fabrics: Part I - Thermal comfort

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Plasma-treated thermal comfort properties of four different types of polyester knitted fabrics (spun, continuous filament, micro denier and hollow fibre polyester), have been studied. The oxygen plasma treatment shows an encouraging effect on the air permeability, thermal conductivity, relative water vapour permeability, and wicking of the fabric samples. The findings mostly depend on the oxygen gas, loop length parameter and the thickness of the fabric. The oxygen plasma treatment also affects the thickness of fabric. The plasma-treated micro denier fabric, having courser count with higher loop length, shows higher air permeability. The plasma-treated hollow fibre polyester fabric has higher water vapour permeability, higher thermal conductivity and the highest wicking height.

Keywords: Knitted fabric, Oxygen plasma, Plasma treatment, Polyester, Thermal comfort

1 Introduction

Besides the mechanical and dimensional properties, comfort property is also essentially required for a fabric. The movement of heat, air and moisture determines the total thermal comfort of the clothing. The heat transfer is done by conduction combined with convection and radiation through the trapped air in the fabric. Mainly, the heat transfer depends on the thermal conduction with negligible convection and radiation losses. Combined heat conduction through air gaps and fibre content is the total heat transmitted through the fabric[1-4]. Plasma-treated fabrics have a faster water absorption rate in the wetting test[1].

The maintenance of thermal balance is probably the most important attribute of clothing, and hence it has drawn the attention of many textile workers[5,6]. The main problem associated with thermal comfort is the incompatibility between the requirement of heat conservation during low metabolic activity and heat dissipation at high energy levels. There are numerous factors that determine the thermal comforts, such as age, sex, adaptation, season and heat-flow conditions as well as physical conditions existing next to skin surface[7,8].

As the environmental factors are enforced on the textile industry, the eco-friendly and economical process developments are of utmost importance for a textile industries. The plasma treatment is an alternate method for the textile industry. Plasma treatments are an energy efficient and environment-friendly processes for altering the surface structure of materials[9]. Without varying the material bulk properties, the surface of the material is modified both physically and chemically by the plasma treatment. Plasma treatment is basically a surface treatment, which does not affect the fibres bulk properties and allows the fabric to maintain its strength after the treatment. This treatment can introduce different types of surface roughness such as cracks and fissures during the modification of fibre surface[10-13]. Moreover, less treatment time and low application temperature, contribute advantages to plasma technology. This is observed as an environment-friendly process, as there are no chemicals, waters or solvents involved in this treatment. Kan and Yuen[14] observed that plasma treatment is a physio-chemical method that is used for surface modification. The surface of the fabric is affected both physically and chemically without altering the fabrics bulk properties. Leroux *et al*.[15] found that atmospheric air plasma treatment for the polyester fabrics has made a significant increase in the water wettability, its surface energy and the water capillarity due to the production of hydroxyl and carboxylic groups. Seki *et al*.[16] showed that O_2 plasma has improved the

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tensile and flexural strength of jute fibre/polyester composites when treated with both the low and radiofrequency plasma system.This paper reports investigation onthe untreated and oxygen plasma-treated single jersey polyester fabrics for further improvement in different comfort properties.

2 Materials and Methods

2.1 Materials

Commercially available four different types of polyester yarns, such as continuous filament, spun, micro denier and hollow fibre, of two different linear densities 111 dtex and 166 dtex were sourced from different resources. Single jersey knitted fabrics were produced using a 21-feed circular knitting seamless machine, KNITMAC 24E gauge, 16 inches' cylinder diameter, special attachment – positive storage feeder and 27 rpm velocity. Three different loop length (LL) settings were kept constant for all the samples at 0.25 cm, 0.27 cm and 0.29 cm respectively.

2.2 Methods

The fabric structural and physical fabric properties, like aerial density (ASTM D 3776), thickness (ASTM D 1777), wales and courses per unit length [ASTM D 3887: 1996 (RA 2008)] and loop length (ASTM D 3887) were evaluated. Air permeability of the fabric has been measured using Textest FX 3300 (Textest Instruments AG, Schwerzenbach, Switzerland) air permeability tester at a pressure of 100 Pa; ASTM D737 has been followed. The water vapour permeability was measured on a Permetest instrument (Sensora Company, Liberec, Czech Republic) according to ISO 11092. The Alambeta instrument (Technical University of Liberec, Liberec, Czech Republic) was used to measure thermal conductivity values. In this instrument, the fabric is kept between hot and cold plates according to ISO 11092. All measurements were performed under the standard atmospheric conditions [21 ± 1 °C (70 ± 2°F) and 65 ± 2% relative humidity (RH)], as recommended by ASTM D 1776.

2.3 Plasma Treatment

Polyester fabric samples were treated in a Diener vacuum plasma device with a flow rate of 500W. The fabric sample (30 cm × 30 cm)was treated with uniform glow discharge plasma. The fabric samples were placed in between the cathode and the anode plate with anelectrode gap of 3 cm. Plasma treatment of the fabric sample was carried out with oxygen in a 12" DC plasma chamber. The samples were treated for about 15 min at a pressure of about 0.5 millibar and a frequency of 0.025 amp. After the treatment, the plasma-treated fabrics were subjected to conditioning for 24 h at 25°C and 65 % RH.

3 Results and Discussion

3.1 Geometrical Properties of Knitted Fabrics

The physical properties of the continuous filament, spun, micro denier and hollow fibre polyester knitted fabric is shown in Table 1. It is observed that there is an increase in the fabric thickness and decrease in the fabric weight when the fabric is exposed to plasma treatment. The electrostatic charges produced by the plasma treatment increases the thickness of the fabric, thereby more voluminous texture is produced in the fibre and yarn structure by rearranging it. An etching phenomenon is observed on the surface of the sample due to the electron and ion bombardment when treated by plasma processing. A very thin layer is directly removed and the interaction of ions with molecules of material is made. The surface contaminant is cleaned from the sample and etching of the fibre takes place when it is treated with plasma, thereby leading to the weight loss of the treated fabric. The effect of plasma is more intense when it is treated for a longer time.

3.2 Surface Morphology

The surface morphology of the polyester fabric was analyzed by SEM image analysis. Figure 1 shows the surface morphology of the untreated, and plasma treated polyester fabrics. It is clearly shown that [Fig. 1(a)] the fibre surface is so even and in Fig. 1(b), it is observed that the fibre surface is etched and grooved by the plasma treatment.

The groves and cracks are formed on the fibre surface after plasma treatment. The plasma treatment displays that the plasma gas could physically modify the surface of the polyester fibre. After the plasma process, the surface is converted rougher.

3.3 Air Permeability

In this study, plasma-treated samples are investigated for air permeability and the results are given in Fig. 2. Certain degree of roughness is produced on the fabric surface due to the plasma treatment, which increases the thickness of the fabric and hence changes the fabric surface characteristics. During the plasma treatment, with the same pressure conditions, it is found that with the increase in loop length, the values of air permeability increase. There is an increasing trend in air permeability, due to the

Table 1 — Physical properties of polyester knitted fabric

Sample (code)	Fineness dtex	Loop length (LL), cm	Fabric thickness, mm		Wales per inch	Coarses per inch	Mass per unit area, GSM	
			Before plasma	After plasma			Before plasma	After plasma
Continuous filament polyester(CF)	111	0.25	0.684	0.692	31	35	121.5	121.0
		0.27	0.678	0.681	29	32	110.2	109.6
		0.29	0.634	0.642	26	30	108.8	108.5
	166	0.25	0.681	0.689	29	37	115.9	115.5
		0.27	0.642	0.647	28	35	104.7	104.0
		0.29	0.643	0.649	26	32	109.4	109.2
Spun polyester (Spun)	111	0.25	0.678	0.686	31	37	113.4	113.1
		0.27	0.645	0.653	27	35	110.1	109.8
		0.29	0.637	0.641	25	34	109.2	108.9
	166	0.25	0.688	0.693	32	35	131.6	131.2
		0.27	0.665	0.676	29	33	129.3	129.1
		0.29	0.644	0.652	25	32	109.5	109.2
Micro denier polyester (MD)	111	0.25	0.656	0.663	33	34	124.4	124.1
		0.27	0.648	0.651	31	34	123.3	122.9
		0.29	0.645	0.654	30	36	121.8	121.4
	166	0.25	0.686	0.695	31	29	117.6	117.2
		0.27	0.662	0.668	27	36	115.5	115.2
		0.29	0.646	0.653	25	35	119.5	119.2
Hollow fibre polyester (HF)	111	0.25	0.689	0.695	30	36	125.1	124.8
		0.27	0.675	0.682	27	35	124.2	123.8
		0.29	0.646	0.655	26	32	115.7	115.4
	166	0.25	0.643	0.652	31	37	121.8	121.4
		0.27	0.638	0.643	30	35	110.6	110.2
		0.29	0.633	0.639	27	33	105.2	104.8

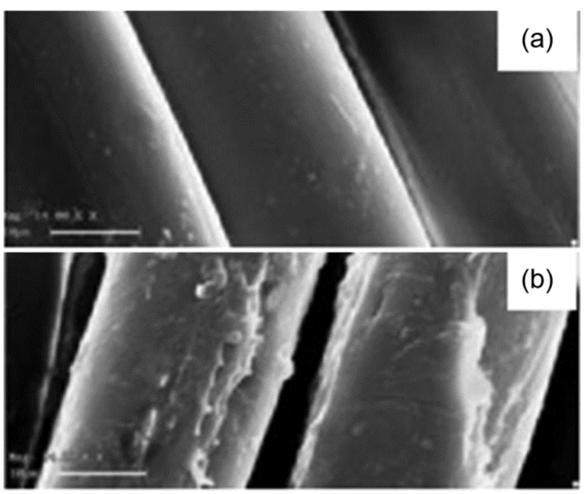

Fig. 1 — Surface morphology of (a) untreated and (b) treated plasma treated polyester fabrics

improved material removal, which is influenced by the plasma action. During the plasma treatment, the surface of the fabric due to etching becomes rough. Hence, it creates more pores in the yarn that will help to transmit more air through the fabric.

The air permeability values of the oxygen plasma-treated samples are given in Fig. 2. The air permeability of 166 dtex spun polyester fabric of 0.25 cm has the lowest value and that of 166 dtex microdenier polyester fabric of 0.25 cm has the highest value among all the fabric samples. The values of air permeability differ based on the filament characteristics and its construction, in which air spaces occupy a large proportion. Fabric thickness and mass per square meter also influence air permeability. The lower the thickness and fabric weight, the higher is the air permeability value[17]. The structure, thickness, and surface characteristics of fabric, have some influence on the air permeability. The fabric structure is not controlled by the plasma action and air permeability depends on the thickness and surface characteristics of the fabric. The surface morphology changes due to plasma treatment and the surface roughness on the fabric has enhanced the air permeability of the fabric.

3.4 Thermal Conductivity

Thermal conductivity is stated as the total amount of heat transferred through the fabric in a standard surface area. Figure 3 shows thermal conductivity of both treated and untreated polyester fabrics. After plasma treatment, the value of thermal conductivity is increased for oxygen plasma. The thermal property of textile fabric mainly depends on the entrapped air within it. Surface etching occurs during the plasma

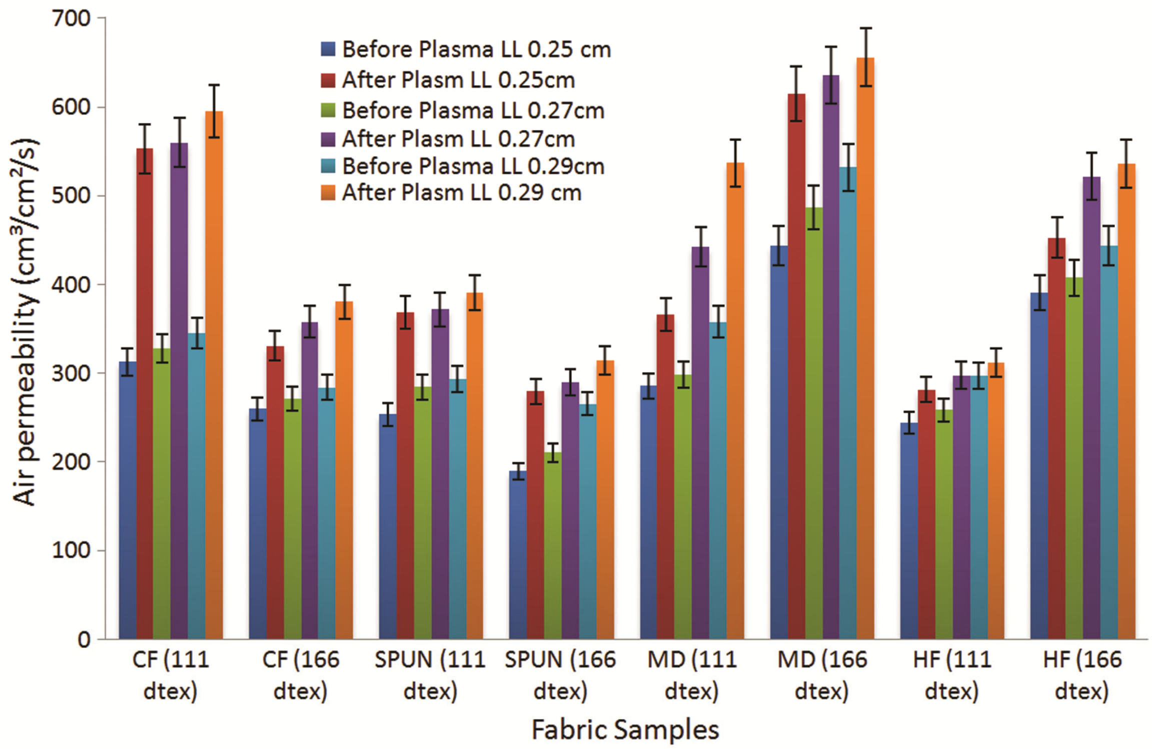

Fig. 2 — Air permeability of oxygen plasma treated polyester fabric

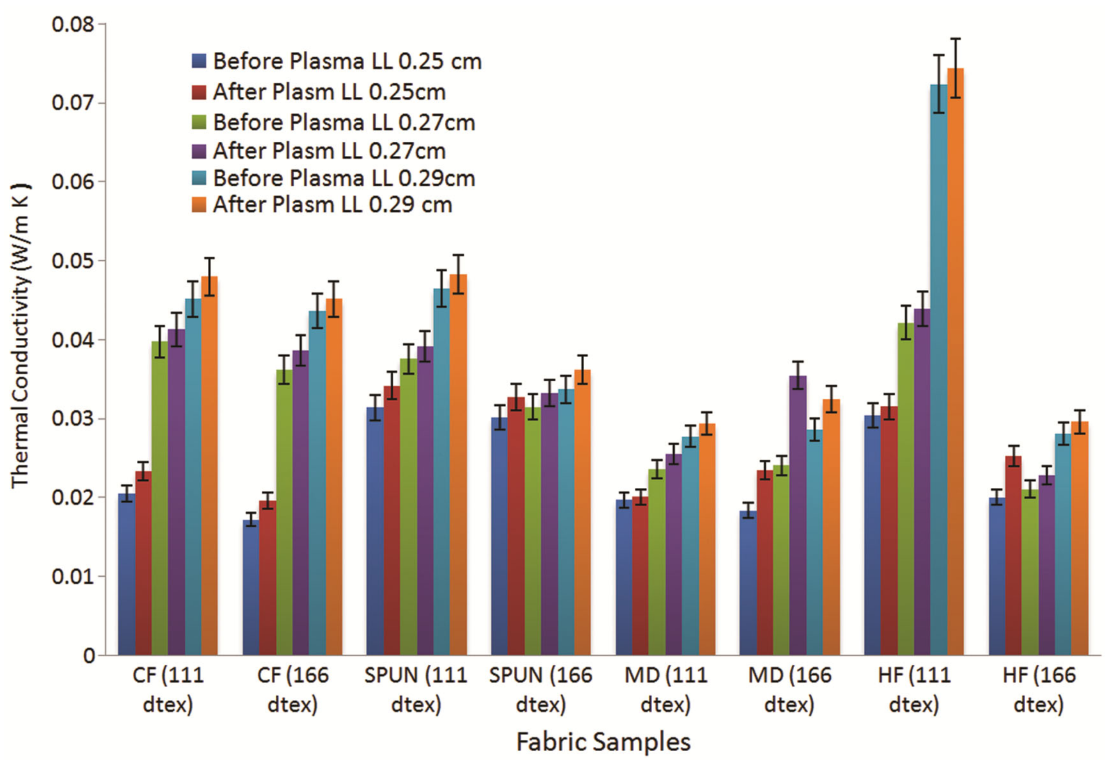

Fig. 3 — Thermal conductivity of oxygen plasma treated polyester fabric

treatment, and the roughness of the surface gets increased. When the surface unevenness increases, the amount of air passing through the filaments decreases and the entrapped air reduces from the surface. Therefore, the entrapped air inside the fabric gets lesser and this implies that plasma-treated polyester fabrics have better conductivity and helps to transfer the heat through the fabric as compared to the untreated polyester fabric[18].

3.5 Relative Water Vapour Permeability

Figure 4 shows that the oxygen plasma treatment improves the water vapour permeability of different polyester fabric samples. It is noted that the increased values of water vapour permeability after the plasma treatment provides sense of comfort.

The water vapour permeability of plasma-treated samples is increased for most of the samples as compared to the untreated fabric samples. This improvement is mostly due to the cracks and grooves formation and surface erosion of polyester fabric by oxygen plasma treatment.

Hence, the plasma-treated fabrics have a better comfort property by controlling the movement of water vapour, as compared to untreated fabric. Certain fibre related factors, such as cross-sectional shape of fibres, moisture absorption and fabric thickness affect the water vapour transmission rate[19].

Similar to the air permeability, water vapour permeability of plasma treated polyester fabric shows higher value of loop length (2.9 cm).

3.6 Wicking

The wicking of the polyester fabric samples of both the oxygen plasma-treated and the untreated fabric is shown in Table 2. A notable improvement in the wicking height of the plasma-treated fabric is observed. This shows the effect of oxygen plasma, which results in etching, activation and cleaning effect on the fabric surface by the oxygen plasma gas during treatment. Oxygen plasma has the capacity to initiate polar groups on the surface of the fabric and remove the hydrophobic contaminants from the surface of the fabric; thereby, producing more

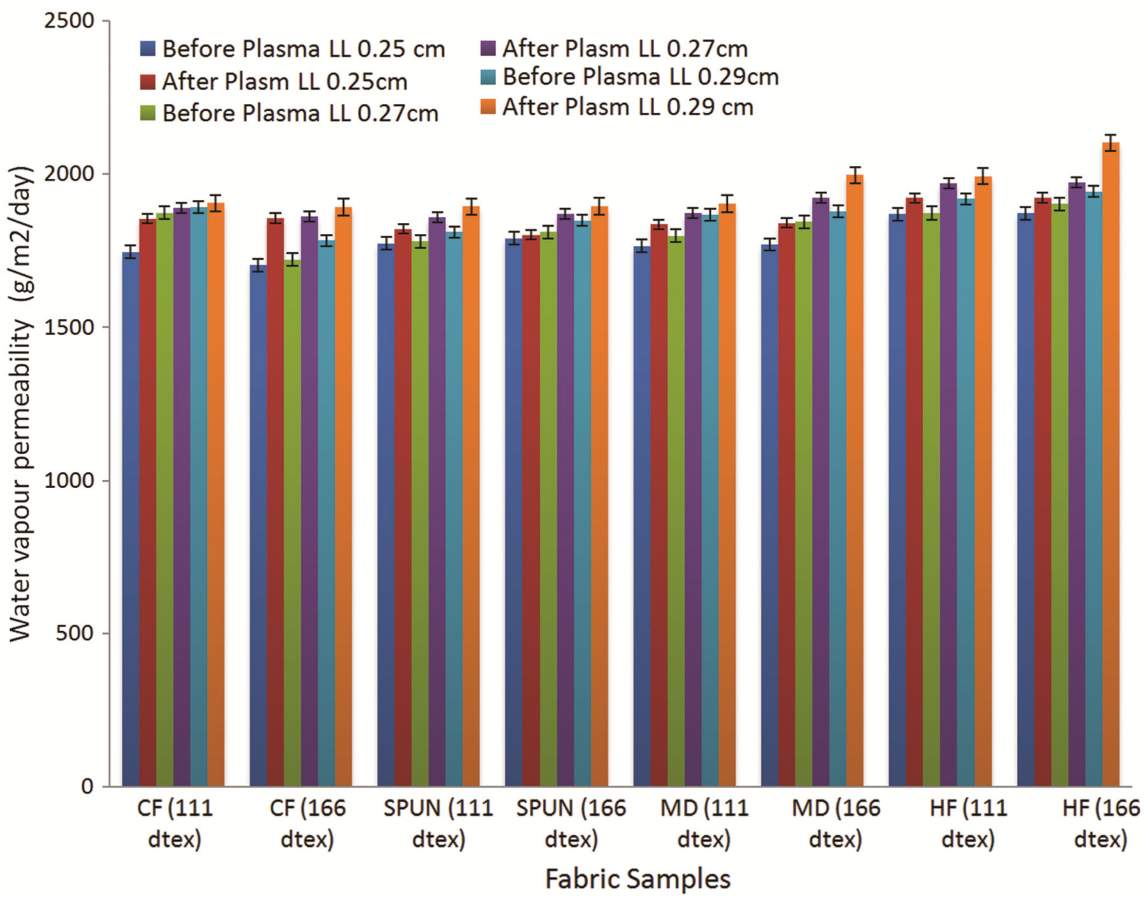

Fig. 4 — Water vapour permeability of oxygen plasma treated polyester fabric

Table 2 — Wicking of different loop length (LL) untreated and plasma-treated polyester knitted fabric after 30 min

Sample	Wicking, cm					
	0.25 LL Saturation point		0.27 LL Saturation point		0.29 LL Saturation point	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
CF (111 dtex)	14	14.5	14.5	14.5	14.5	16
CF (166 dtex)	19	19	20	20	19	20.5
Spun (111 dtex)	5	5	6	6	5.5	7
Spun (166 dtex)	5.5	6	6.5	7	5.75	7.5
MD (111 dtex)	18	19	19	20	19	21.5
MD (166 dtex)	19.75	20	20	20	20	20.5
HF (111 dtex)	19.75	20	20.5	21	20	21
HF (166 dtex)	19.75	19.75	20.75	21	14.5	21

hydrophilic fibre surfaces. Due to the hydrophilic nature of the fibres, the fabric provides better comfort by maintaining the moisture; whichever it comes from the surrounding environment or the body. The wicking behaviour of the continuous filament polyester sample is higher than the spun polyester sample. This is due to the fact that capillaries are better in continuous filament yarn than in the randomly arranged spun yarn. The number of fibres in the cross-section and the length of the fibre also play a major role in the wicking behaviour. The low wicking in the spun polyester sample is due to the disturbances in the continuity of the capillaries[20]. For a single jersey fabric, the wicking length increases with an increase in stitch length[21]. This study shows that it is possible to improve the wicking property of polyester fabric by treating it with oxygen plasma. The alteration on the surface of the fabric might decrease the capillary pressure, and thereby increase in the functional groups on the surface of the filament that might be the reason for the increase in wettability.

4 Conclusion

In this study, the thermal comfort properties of four different types of polyester knitted fabrics (spun, continuous filament, micro denier and hollow fibre polyester) are investigated. The oxygen plasma treatment shows an encouraging effect on the air permeability, thermal conductivity, relative water vapour permeability and wicking for the fabric samples. The findings mostly depend on the oxygen gas, loop length parameter and the thickness of the fabric .The oxygen plasma treatment has an effect on the thickness of the fabric. There is an increase in the thickness of the fabric after the plasma treatment. After the plasma treatment, air permeability values of the fabric is increased. The microdenier fabric of 166 dtex of 0.29 cm loop length treated with oxygen plasma has higher air permeability as compared to the other fabric samples. The hollow fibre polyester fabric(0.29 loop length of 166dtex) has higher water vapour permeability as compared to the other fabric samples. After the plasma treatment, the hollow fibre polyester fabric (111dtex of 0.29 cm loop length) treated with oxygen plasma has higher thermal conductivity. The hollow fibre polyester fabric treated with oxygen plasma has the highest wicking height and the spun polyester fabric has the lowest wicking height.

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